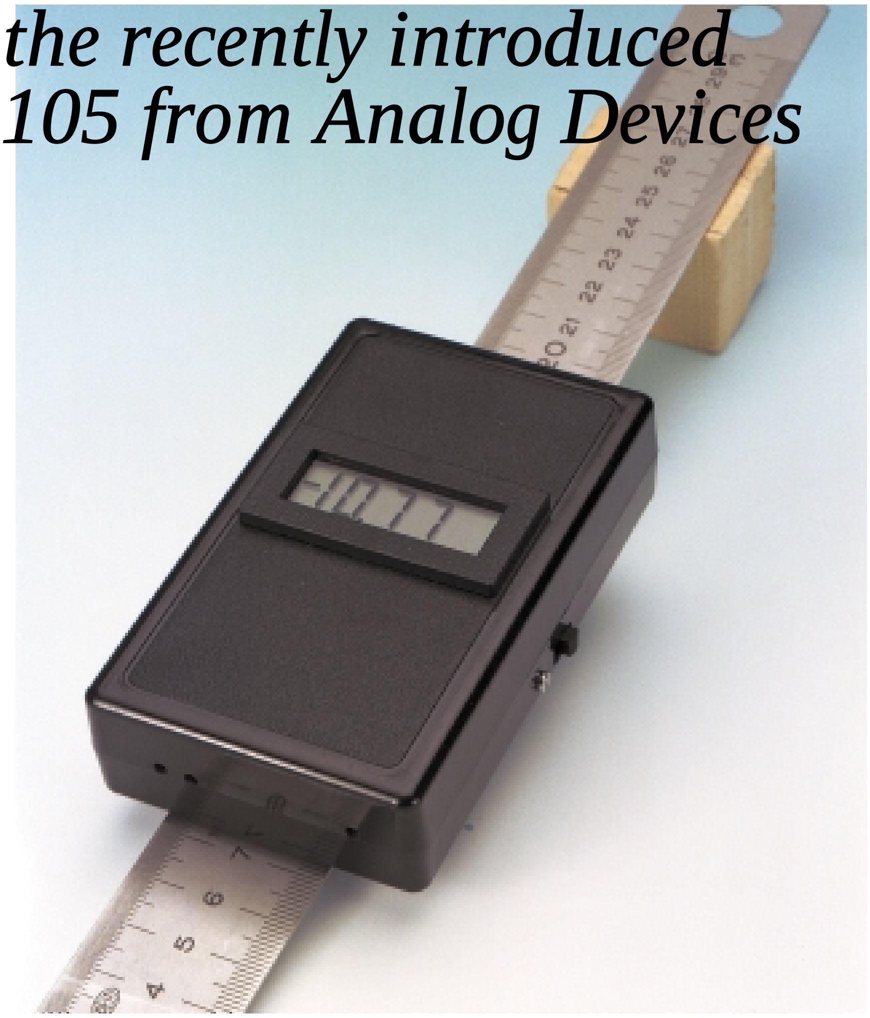
gradient* meter

based on the recently introduced Type ADXL105 from Analog Devices

An integrated accelerometer circuit such as the ADXL105 from Analog Devices, although intended primarily for measuring acceleration and deceleration, may readily be used for gauging gradients*. If the circuit is to be used out of doors, its temperature compensation must be adapted accordingly.

Design by P. Porcelijn



INTRODUCTION

The Type ADXL05 accelerometer IC from Analog Devices was introduced in a relevant Application Note in the April 1997 issue of *Elektor Electronics*. Just over a year later, the device was used as the basis of an ‘electronic accelerometer’ (June 1998 issue of *EE*).

From the properties of the circuit it is clear that the device may readily be used for measuring gradients. When this is to be done with some accuracy in a motor vehicle or on a bicycle, it is, of course, necessary to maintain a constant speed.

There are two further matters to be resolved before gradients can be gauged with an accelerometer: the choice of a suitable display, and adding suitable temperature compensation.

The question of a display is relatively easily satisfied. This is achieved by obtaining a direct indication of the percentage gradient from the relationship between the acceleration of free fall, *g*, the gradient, *p*, in per cent, and adjusting the amplification of the circuit accordingly. From the discussion in the box ‘Principle of measurement’ it will be seen that, within narrow tolerances, the output voltage of the sensor is virtually directly proportional to the gradient percentage.

Solving the matter of temperature compensation is rather more tricky. Compensation is necessary because when the device was tested for use as a gradient gauge on a bicycle it was found that temperature variations caused such inaccurate measurements as to render them unusable.

Fortunately, Analog Devices recently upgraded the ADXL05 to the Type ADXL105, which is provided with an internal temperature sensor. The addition of a few simple electronic circuits to the sensor gives the upgraded device very efficient temperature compensation.

CIRCUIT DESCRIPTION

The circuit diagram is shown in **Figure 1**. It will be seen at a glance that, like the earlier accelerometer, the gradient meter is battery operated. Also, the display is again formed by a Type DPM951 digital voltmeter (DVM) linked to the circuit via box header K_1.

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* *Also, especially in USA and Canada, grade: a part of a road or railway that slopes upwards or downwards, an incline. It also indicates the measure of such an incline (normally as a percentage).*

It will also be seen that, whereas the accelerometer comprises just the ADXL05 chip and the DVM module, the gradient meter has two additional operational amplifiers (op amps), one of which is needed for the temperature compensation circuit.

According to the manufacturer's specification, the temperature drift of the ADXL105 is about 1 mV $°C^{-1}$, that is, roughly 60 mV over the entire temperature range. Since the error in the gradient meter is amplified ×4, the overall drift works out at 4 mV $°C^{-1}$, which, as the polarity of the temperature coefficient is not known, will lead to unusable results.

The integral temperature sensor of the ADXL105 provides a temperature-dependent voltage, U_t, at output T_{out} (pin 1) of

$$U_t = 2.5 + 8\times10^{-3}\times(t-25) \quad \text{[V]}$$

with a tolerance of ±0.1 V (t is the ambient temperature).

The output of the sensor is modified to a usable value with the aid of a compensating circuit based on op amp IC_{3b}. This circuit enables the temperature coefficient to be set between –8 mV $°C^{-1}$ and +8 mV $°C^{-1}$ with P_1. In principle, a passive circuit could have been used, but that would have made the calibration fairly tedious.

Unfortunately, the integral potential divider in the ADXL105 has an output impedance of 10 kΩ. This is rather high for the present application, particularly since the output voltage is also used for the DVM module. This small problem is remedied by a buffer, op amp IC_{3a}.

OFFSET AND GAIN

The passive components in the circuit diagram not yet dealt with form part of the offset compensation and requisite amplification circuits.

The offset error of the ADXL is not insignificant: it may be as high as ±625 mV. Fortunately, compensating for this is easily achieved by injecting a variable direct current into V_{IN} (pin 11) via resistor R_5 and preset P_2. At unity gain, the range of this preset is ±870 mV.

The input range of the specified DVM module is 200 mV. Assuming that the maximum gradient (grade) to be

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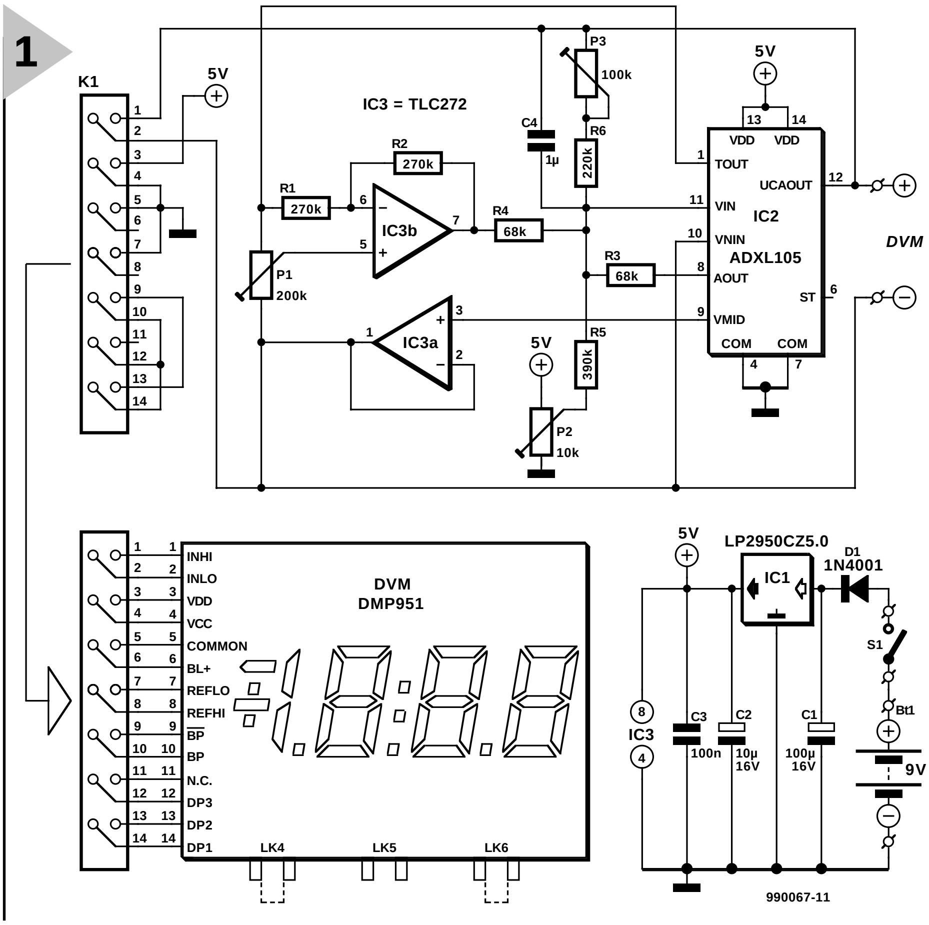

Figure 1. Other than the accelerometer IC and the digital voltmeter (DVM) module, the electronics is limited to two operational amplifiers and some passive components.

Figure 2. Printed-circuit board for the gradient meter which is, however, not available ready made.

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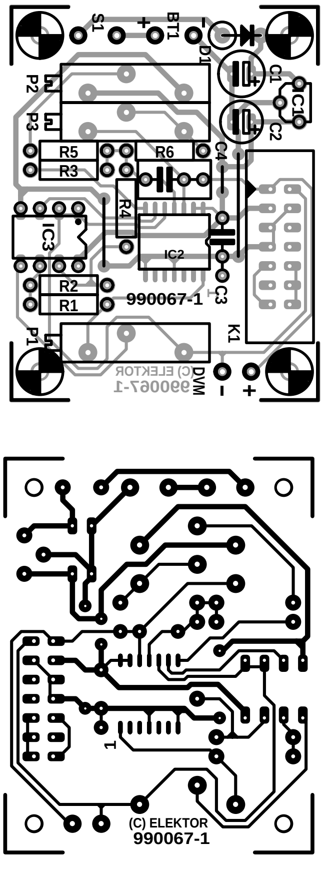


Parts list

Resistors:
R_1, R_2 = 270 kΩ
R_3, R_4 = 68 kΩ
R_5 = 390 kΩ
R_6 = 220 kΩ
P_1 = 200 kΩ, 10-turn preset
P_2 = 10 kΩ, 10-turn preset
P_3 = 100 kΩ, 10-turn preset

Capacitors:
C_1 = 100 µF, 16 V, radial
C_2 = 10 µF, 16 V, radial
C_3 = 0.1 µF, ceramic
C_4 = 1 µF, metallized polyester

Semiconductors:
D_1 = 1N4001

Integrated circuits:
IC_1 = LP2950CZ5.0
IC_2 = ADXL105JQC
IC_3 = TLC272CP

Miscellaneous:
BT_1 = 9 V battery with connecting clips
S_1 = slide switch, 1 make contact
K_1 = 14-way box header
DVM module as appropriate
Enclosure as appropriate

principle of measurement

Owing to the earth’s gravity, any freely suspended object is subject to an acceleration of free fall, g, which, near the earth’s surface, is equivalent to 9.80665 m s^{-2}. If the object is on a gradient of p%, its acceleration, g_s is

$$g_s = g \sin\alpha, \qquad [1]$$

where α is the gradient, and

$$\sin\alpha = p/100/\sqrt{1+(p/100)^2} \qquad [2]$$

If $p/100 << 1$, this equation simplifies to

$$\sin\alpha \approx p/100. \qquad [3]$$

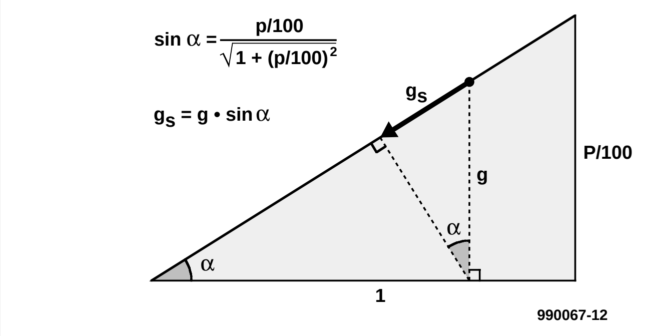
When the latter equation is used, a small error occurs :

0.5% when $p = 10\%$
2% when $p = 20\%$

Since the error remains within acceptable limits, equation [3] is perfectly all right for practical use.
Combining equations [1] and [3] gives the following relationship between acceleration and gradient:

$$p = (g_s/g) \times 100\%$$

This equation shows that if a small error is acceptable, the output voltage of the accelerometer IC is directly proportional to the gradient.


$\sin\alpha = \frac{p/100}{\sqrt{1+(p/100)^2}}$
$g_s = g \cdot \sin\alpha$
g_s
g
P/100
α
α
1
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traversed is 20% (a steeper incline is seldom encountered on normal roads), these two quantities can be equated very satisfactorily.

Since the sensitivity of the accelerometer IC is 0.25 V g^{-1}, its output voltage in volts is a quarter of the maximum gradient in per cent. This means that all that needs to be done is to make the output voltage of IC$_2$ in volts equal to the gradient in per cent. A simple calculation shows that this requires an amplification of ×4, which is set with resistors R$_3$ and R$_6$. Any tolerances are compensated with preset P$_3$ in series with resistor R$_6$. Any interference is minimized by capacitor C$_4$, whose value is chosen such that the reaction of the circuit to varying circumstances is not unduly delayed.

CONSTRUCTION

Building the gradient meter on the printed-circuit board in **Figure 2** is straightforward. Note, however, that this board is not available ready-made. Care should be taken to ensure that the sensor is soldered level on the board, since for correct operation it must be parallel with the board.

The voltmeter module is linked to the circuit via box header K$_1$. If a module other than specified is used, it may be possible to omit K$_1$ and solder the module terminals directly to ‘DVM’ on the board.

The completed board fits nicely in the specified enclosure. Note that the fixing bosses in the enclosure are not used: the board is simply screwed directly to the bottom. Good care should be taken because it is a tight fitting.

Before the board is fitted in the case, drill three holes in the top lid so that presets P$_1$–P$_3$ are accessible from the outside.

POWER SUPPLY

The DVM module is powered by a 9 V dry or rechargeable battery. The battery voltage is reduced to 5 V by voltage regulator IC$_1$. Since the accuracy of the voltmeter is wholly dependent on the supply voltage, the regulator should be a type with very low temperature coefficient: better than 150 ppm °C^{-1}. The type specified is also a low-drop model which makes it ideally suited for use in battery operated equipment.

The gradient meter draws a current of about 6 mA. Diode D$_1$ guards against incorrect polarity of the supply lines.

CALIBRATION

Offset & temperature compensation

1. Place the gradient meter in a level position (check with a spirit level) in a constant ambient temperature of 20 °C and leave it to settle down for about half an hour.
2. Set P$_3$ to the centre of its travel. Connect a digital voltmeter (direct millivoltage range) between ‘–DVM’ and pin 7 of IC$_3$. Adjust P$_1$ until the meter reading is exactly 0.
3. Turn P$_2$ until the DVM module also reads exactly 0.
4. Heat the gradient meter with, say, a hair dryer, whereupon the reading on the DVM will probably change. Readjust P$_1$ until the module again reads exactly 0.
5. Let the gradient meter cool off for about half an hour and, if necessary, readjust P$_2$ until the DVM module reads exactly 0.
6. Repeat steps 4 and 5 until a satisfactory temperature compensation is obtained.

Amplification

The amplification should be set with the gradient meter on a gradient (grade). The discussion in the box shows that the approximation $\sin\alpha \approx p/100$ has an error that increases in direct proportion with α. For instance,

at $p \approx 0\%$, the error is 0%,
at $p \approx 10\%$, the error is 1%,
and at $p \approx 20\%$, the error is 2%.

The error may be minimized by calibrating at about the centre of the measuring range, rather than at the extremes. A simple calculation shows that the maximum error can be brought down to 1% if calibration takes place at a gradient of about ×1/1.4 (0.712) the maximum. So, if the maximum is taken as 20%, calibration should take place at a gradient of 14%.

The gradient is readily obtained by fixing (adhesive tape) the gradient meter at the centre of a 1 metre (39.3 in) long strip of straight wood. A gradient of 14% is obtained by placing one end of the strip of wood 14 cm higher than the other end. When this is done, adjust P$_3$ until the DVM module reads the percentage gradient of 14%.

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